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Description

SPORTING EQUIPMENT PROVIDED WITH A MOTION DETECTING ARRANGEMENT

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of United States Provisional Application No. 60/319,580 filed 27 September 2002 and claims priority to Swedish Application No. 0202873-6 filed 27 September 2002. Said provisional application is expressly incorporation herein by reference in its entirety.

BACKGROUND OF INVENTION

TECHNICAL FIELD

[0002] The present invention relates to sporting equipment provided with an arrangement for detecting, tracking and analyzing motion parameters of the equipment.

BACKGROUND

[0003] A general Inertial Navigation System (INS) consists of both hardware and software. The hardware is a well-defined

collection of sensors that detect all possible accelerations and rotational velocities, in all relevant room coordinates. Usually, the sensors are accelerometers and gyroscopes. The task of the software is to compute the movement-parameters, like position and orientation of the hardware, while also carefully keeping track of coordinate transformations during the motion. It is this coordinate transformation property that distinguishes an INS from a sensor system that only integrates accelerometer and gyro signals.

[0004] The basic movement-parameters are the velocity, position, angular acceleration and orientation in a specific coordinate system. To be useful, this coordinate system must be fixed with respect to the earth for reasons that will become more obvious after studying the example in a later section. For a golf club, with an INS mounted to the butt of the shaft, the shaft can then tracked with respect to, for example, the associated golf ball. It is also reasonably straight forward to understand that other parts of the club may be tracked, through a pure mathematical translation, as long as the response of the club material between the mounting point and the tracking point is known. If the club is assumed to be a rigid body, then any

part of the club can easily be tracked. Furthermore, the movement-parameters must be resolved in the three room (the x-y-z) coordinates and also resolved in time. The basic movement-parameters can now easily be re-computed to any other interesting parameters such as player hand speed, various angles and speeds with respect to the swing plane, or anything that mathematical combination or translation will allow from the basic movement-parameters and the originally measured parameters.

[0005] One of the objects of the present invention is to provide an arrangement including such an INS for utilization in the play of sports, including automotive sports, leisure sports, toys and the like. Most especially, the present invention relates to an arrangement for sporting devices such as golf clubs, but other arrangements such as tennis rackets, hockey sticks, baseball bats and the like may also utilize and benefit from the teachings of the invention. Consequently, the invention includes quantifying and storing: movement information as variable values, computed results and movement-parameters from the INS sensors. Accordingly, it is possible to use the variables in real-time applications, or store the variables for later analysis.

[0006] It is useful to consider a simplified system to obtain an intuitive feeling for what an INS does with raw sensor signals and hence the difference between a collection of sensors and an INS. A simplified system can consist of, for example a ship that starts moving, sails straight, makes a U-turn, and comes back on a path parallel to the original straight course. While doing all this, even through the U-turn, the ship accelerates with a constant acceleration.

[0007] An accelerometer rigidly mounted to the ship, in the direction of travel, will produce a signal looking like a straight horizontal line. Integrated once, this signal will yield the velocity. By integrating the signal again, the position of the accelerometer is obtained. It is impossible to see any turning of the boat from this position trace, in fact, nothing but a constantly accelerating motion can be deduced from any of these traces. If the boat would have omitted the U-turn and kept sailing absolutely straight forward, with the same acceleration as in the first case, all the curves would have appeared identical to the original case.

[0008] However, the result is not an error; the accelerometer shows a signal relevant to its own co-ordinate frame. The U-turn is only relevant for an observer that can relate the

boat to an outside object that does not turn, like the water or a shoreline. The accelerometer is simply not "smart" enough to know, in that it has no capability for determining that it has turned.

[0009] The accelerometer mounted to the deck, measures acceleration in the sensor system. The task is then to convert this measurement to a fixed system outside the boat, the navigation system. Unless this conversion is done properly, the answer expressed in the navigation system, which is the useful system to an observer, will be wrong.

[0010] The remedy is to equip the boat with additional sensors. In the illustrative case of the boat, only one more accelerometer (accelerometer y), and perhaps one more gyroscope need be added. Generally speaking, the boat can never sail in the z-direction (up-down) and it can only turn around the z-axis (on the water surface). By further adding INS software and hence completing the INS, the INS can keep track of turns and therefore correctly transform sensor signals from the boat co-ordinate system to a global coordinate system that views the boat relative to the water or land and which will be generally termed the navigation system. Of course, the velocities in the x and y-directions are also readily available.

[0011] This simplified system does not consider any wave action, however. When a wave hits the boat, the entire INS can move up and down. A movement strictly in the z-direction will not affect the INS because it is irrelevant if the boat travels exactly on the water surface or one meter above it, as long as all the original maneuvering stays the same. If the boat rocks sideways, however, then the INS will tilt with respect to the water surface or at least with respect to the coastline. The x-axis accelerometer, for example, will then point in a new and unknown direction with respect to the coastline. Hence, the INS will be unable to correctly compute its position and orientation with respect to land. The best way to get around this problem is to add two more gyroscopes and one more accelerometer to the system. Now, the boat can rock and roll and in principle all the movement-parameters will be "accurately" measured.

[0012] The INS is usually used in aircrafts. For example, according to US 6,285,954, strap down inertial navigation systems are frequently used in missiles and aircraft. Physically isolated and stabilized apparatus, such as a gimballed platform that is physically angularly stabilized relative to the local vertical direction, require precise and me-

chanically complex angle positioning apparatus, and are being systematically replaced by systems of the strap down type.

[0013] A state-of-the-art strap down inertial navigation system has three rotation sensors or gyros and three accelerometers rigidly attached to a supporting vehicle. The rotation sensors are each positioned and oriented to sense angular displacement about one of three defined orthogonal axes attached to the vehicle body and known as the body coordinate system. The accelerometers are each positioned and oriented in a fixed direction relative to the vehicle in order to sense velocity changes (incremental velocities) along three different orthogonal axes in the body system. In a strap down system, the accelerometer axes are not angularly stabilized. Hence, all inertial sensors output a raw signal meaningful in the body coordinate system.

[0014] Typically, the accelerometers are constantly changing direction relative to gravity, navigation velocities cannot be computed by directly integrating the accelerometer signals. Instead, a stable computational frame or analytic navigation coordinate system is continually computed. The output signals from the rotation sensors are used by an attitude integration apparatus to calculate the direc-

tions of local vertical, together with two other axes orthogonal to the local vertical direction.

[0015] Sensed angle changes and accelerations (incremental velocities) are continually rotated through the calculated angles from the vehicle body axes to the calculated navigation axes. Angle signals from the rotation sensors are used to update the computer-stored angular position and incremental velocity data for both the angle sensors and accelerometers relative to the navigation coordinate system.

[0016] The rotation sensors and accelerometers have fixed relative directions in the body coordinate system. An angular transformation matrix of direction cosines is computed in an attitude integration apparatus. The accelerometer signals, which are incremental changes in velocity, in the strap down body coordinate system are converted in a coordinate transformation computer from that system into corresponding signals in the stabilized navigation coordinate system.

[0017] After transformation into the navigation coordinate system, the incremental velocity signals are integrated or summed to form updated velocity signals. The rotation sensor and accelerometer signals are sampled, and the

sampled signals are delivered to a computer which is programmed to accept the signals and to calculate both velocities along the three axes in the stabilized navigation coordinate system and attitude angles relative to this system.

[0018] In US 4,303,978, a plurality of inertial measuring unit (IMU) modules, each comprising (including, but not limited to) gyros and accelerometers for sensing inertial information along two orthogonal axes, are strapdown-mounted in an aircraft, preferably such that the sense axes of the IMUs are skewed with respect to one another. Inertial and temperature signals produced by the IMU modules, plus pressure signals produced by a plurality of pressure transducer modules and air temperature signals produced by total air temperature sensors are applied to redundant signal processors. The signal processors convert the raw analogue information signals into digital form, error compensate the incoming raw digital data and, then, manipulate the compensated digital data to produce signals suitable for use by the automatic flight control, pilot display and navigation systems of the aircraft. The signal processors include: an interface system comprising a gyro subsystem, an accelerometer and air

calibration data subsystem and an air data and temperature subsystem; a computer; an instruction decoder; and, a clock. During computer interrupt intervals, raw digital data is fed to the computer by the interface subsystems under the control of the instruction decoder. The computer includes a central processing unit that compensates raw digital gyro and accelerometer data to eliminate bias, scale factor, dynamic and temperature errors, as necessary. The central processing unit also modifies the gyro and accelerometer data to compensate for relative misalignment between the sense axes of the gyros and accelerometers and for the skewed orientation of these sense axes relative to the yaw, roll and pitch axes of the aircraft. Further, accelerometer data is transformed from body coordinate form to navigational coordinate form and the result used to determine the velocity and position of the aircraft. Finally, the central processing unit develops initializing alignment signals and develops altitude, speed and corrected temperature and pressure signals.

[0019] WO 00/69528 relates to an instrumented golf club system having an instrumented golf club, an interface means and a computing means is disclosed herein. The instrumented golf club includes a plurality of sensors, an internal power

supply, an angular rate sensor and an internal ring buffer memory for capturing data relating to a golf swing. The interface means is capable of transferring data from the instrumented golf club to the computing means for processing the data and presenting the data in a useful and informative format. The data may be used to assist a golfer's swing, or to design an appropriate golf club for a specific type of golfer.

[0020] However, although the invention points out a need for high precision and includes a rate sensor, the initial system orientation with respect to gravity is never considered. This collection of sensors fails all of the three points for a successful INS, particularly for an INS useful for adapting golf clubs.

[0021] WO 02/38184 is directed to systems and methods for analyzing the motion of sporting equipment, such as a golf club, a baseball bat, a hockey stick, a football or a tennis racquet, for example. The systems comprise a motion sensing system in communications with the sporting equipment to measure motion parameters wherein the motion sensing system has at least one accelerometer or at least one gyroscope, and a command station having a data acquisition system to process the measured motion

parameters and produce data. The motion sensing system may be located on the sporting equipment or, optionally, within the sporting equipment. The systems and methods described herein can be used to determine the impact location of the sporting equipment with another object, the experienced forces, the velocity of the sporting equipment and/or angular orientation of the sporting equipment during a motion.

[0022] US 6,157,898 describes a device for measuring a movable object, such as a baseball, football, hockey puck, soccer ball, tennis ball, bowling ball, or a golf ball. Part of the device, called the object unit, is embedded, secured, or attached to the movable object of interest, and consists of an accelerometer network, electronic processor circuit, and a radio transmitter. The other part of the device called the monitor unit is held or worn by the user and serves as the user interface for the device. The monitor unit has a radio receiver, a processor, an input keypad, and an output display that shows the various measured motion characteristics of the movable object, such as the distance, time of flight, speed, trajectory height, spin rate, or curve of the movable object, and allows the user to input data to the device.

[0023] According to the disclosed invention of US 6,157,898, only one accelerometer network is used to measure the acceleration in distance/time and thus the system provides poor precision. Moreover, the invention of US 6,157,898 is to be integrated within a ball or similar object and not likely for a golf ball and the like.

SUMMARY OF INVENTION

[0024] One of the objects of the present invention is to provide an arrangement comprising an INS, rate sensors, inclinometers and temperature sensors for sports equipment, leisure equipment, toys and the like. Most especially, the present invention relates to an arrangement for sporting equipment such as golf clubs, but other equipment pieces such as tennis rockets, hockey sticks, and the like can also employ the teachings of the invention.

[0025] Thus, an object of the invention is to use motion parameters to provide better practicing, playing and competition ability. Preferably, information received from the sensors is resolved, for example, into three room-coordinates (x-y-z), and even with respect to time. Consequently, an "all in one" quantifying and storing of a movement is possible by computing results and variables from the sensors. Accordingly, it is possible to use variables in real-time

applications or for later analysis.

[0026] The invention has many advantageous applications. One example is its capability to quantify the repetitive motion or motion patterns experienced when learning to play a sport which can be used to expose errors and shortages in motion and store a motion pattern or variables, comparing motion pattern and variables with stored data, to compare the data with results or performances (something accomplished).

[0027] Using the stored data can help the development of better tools and equipment that improve the movement patterns of the user.

[0028] Using the arrangement of the invention, for example in a golf club, permits a teacher, when satisfied with a pupil's swing, to store the motion pattern. Then, the pupil can, at anytime, train his or her swing by comparison with the stored data. Errors and defects thereby become obvious.

[0029] The pupil and the teacher can compare the results of the swings, for example hooks or slices, with the quantified movements and or conclusions with it conclusions quantify the gesture and pull development. A classical kind of feedback.

[0030] The player obtains feedback directly in the quantified mo-

tion about various news in the swing or the equipment. This information can be a different range between the leg and the boll, a different power in the swing, angle of the wrist before the forward motion, a new grip of the handle, a new club, different shows or different ground.

[0031] The feedback can be obtained after follow-up analysis, or also through a signal before, during or after the motion. These signals can be triggered by differences in computed parameters in the stored motion and actual motion. This can be used to practice driving position, part of movement or body orientation during the swing.

[0032] A user can compare his swing with an expert swing.

[0033] Characteristics of a swing can be translated to quantified parameters, thus allowing other judgment possibilities.

[0034] Another object of the invention is to compensate for the ambient temperature of the equipment using the arrangement of the invention.

[0035] Therefore, in arrangement described above, parameters regarding acceleration and angular velocity of the object are deduced. The arrangement includes an Inertial Navigation System (INS) having at least one gyroscope and accelerometer for measuring an acceleration, angular velocity and effect of attraction of gravity on said object. The

arrangement comprises means for communicating with a computer unit for receiving and storing relevant data. The arrangement comprises means for communicating with a computer unit for compensating for said effect of attraction of gravity.

[0036] Most preferably, the data quantifies a movement by computing results and variables from said sensors.

[0037] In a preferred embodiment, a minimum sensor set up comprises at least one accelerometer, temperature sensor, gyroscope, amplifiers and filters. The accelerometer and gyroscope form a time dependent sensor inputs to said INS.

[0038] According to a preferred embodiment, the signals from sensors are generally filtered in filters and amplified in amplifiers before they form inputs to an INS filter. At least one of the filters is an extended Kalman filter, comprising a sensor model, a measurement noise model, a processor for dynamics and a processor for noise model. Calibration data is used regarding offsets, scale factors and the directions of sensitivity of physical sensors. Preferably, estimated output parameters, represented by a vector matrix, are one or several of orientations, angular velocities, angular accelerations, positions, velocities, and accelerations

respectively, which variables represent time dependent results from the INS.

[0039] Most preferably, the object is sporting equipment such as a golf club.

[0040] Preferably, three coordinate systems are used: a navigation system, a club system and a sensor system. The navigation system defines a position of the club, typically as an angle of the club head with respect to a ball. The sensor is arranged in at least one of a handle, shaft or head of the golf club.

[0041] The computer unit provides for at least one of: computing and storing movement data about the equipment, or comparison between new and stored movement data.

[0042] The invention also relates to a system for detecting and analyzing motion data comprising acceleration and angular velocity. The system comprises an arrangement for detecting movement-parameters of an equipment piece. The arrangement comprising an Inertial Navigation System (INS) that has a number of sensors: at least one gyroscope and accelerometer for measuring acceleration and angular velocity and effect of attraction of gravity on the equipment, a computer unit communicating with the arrangement and comprising processor for processing data re-

ceived from the arrangement and compensating for the effect of attraction of gravity on the equipment.

[0043] Preferably, the computer unit comprises an audio and a video output arrangement for communication with a user of the equipment. The computer unit comprises storing means for storing data from the arrangement and providing the data for education or training of the user. The equipment (piece) is exemplarily one of a golf club, ice-hockey stick, baseball bat, tennis/badminton/table tennis racket, and/or a fishing rod.

[0044] Preferably, the sensor system has a specific coordinate system, which is transformed to a fixed coordinate system with respect to a fixed point in an environment of the equipment.

[0045] In one embodiment, the invention also relates to a golf club comprising an arrangement for detecting movement-parameters of the golf club. The arrangement comprises an Inertial Navigation System (INS). The arrangement further comprises a number of sensors for measuring an acceleration, angular velocity and effect of attraction of gravity on the golf club. The club also comprises means for communication with a computer unit for receiving and storing relevant data. The club also comprises means for

communication with a computer unit for compensating for the effect of attraction of gravity. Preferably, the data quantifies a movement by computing results and variables from the sensors. A minimum sensor set up comprises at least one accelerometer, temperature sensor, gyroscope, amplifiers and filters. The accelerometer and gyroscope form time dependent sensor inputs to the INS. The actual sensors are generally filtered in filters and amplified in amplifiers before they form inputs to an INS filter. The filter is an extended Kalman filter, comprising a sensor model, a measurement noise model, a processor for dynamics and a processor for noise model. Preferably, the club uses calibration data comprising offsets, scale factors and directions of sensitivity of physical sensors. The estimated output parameters, represented by a vector matrix, are orientations, angular velocities, angular accelerations, positions, velocities, and accelerations respectively, which variables represent the time dependent results from the INS. Most preferably, three coordinate systems are used: a navigation system, a club system and a sensor system. The navigation system defines a position of the club an angle of a club head with respect to a ball. The sensor is arranged in at least one of a handle, shaft or head of the

golf club.

[0046] Preferably, when tracking at an end of a shaft, a position is about ≤10 mm, preferably within 5 mm throughout an entire swing. All angles at the end of the swing are within 2°, and preferably within 0.5 to 1°. Linear and angular velocities of the club are within 2%, preferably within 1% of its maximum values. A sample rate exceeds 120 samples/sec., preferably 250 samples/second to resolve a final part of the motion. When tracking at the club head, the position is within 10 mm, preferably within 2-5 mm. A loft/lie angle is within ±1°, preferably within ±0.5°. An open/close angle is resolved to within ±0.5 °, preferably within ±0.1 °. Angular rates are, within about 2% preferably within 1% of their maximum values. A linear velocity is within 1 mph, preferably 0.5 mph.

[0047] The invention also relates to a method of analyzing a movement of a sporting equipment piece comprising, the steps of: collecting movement-parameters of the equipment by means of an Inertial Navigation System (INS), by measuring acceleration, an angular velocity and effect of attraction of gravity on the equipment. The method further comprises the step of compensating for the effect of attraction of gravity. Most preferably, the equipment is a

golf club, comprising gyro sensors and accelerometer sensors.

[0048] The method comprises the steps of: prior to a swing, initializing the INS by holding the club substantially absolutely still in a well-defined position, removing offsets of the gyros in the club by keeping them still, and removing offsets of the accelerometers by comparison to the known effect of gravity on each sensor.

[0049] The method comprises the further steps of: immediately prior to a swing, aiming at a ball in a direction of a flag for the sensors to define a direction toward the flag, continuously activating the sensors in a back swing and measuring accelerations and rotational velocities. The method also comprises the step of measuring temperatures.

[0050] The method further comprises the steps of: collecting data unit the data is discriticizes, performing rudimentary signal processing, and storing the data in an internal memory.

[0051] Preferably, all stored data is transferred to a computer unit after a performed swing. A three dimensional acceleration and angular velocity are measured.

[0052] The invention also relates to a golf club comprising, an arrangement for detecting movement-parameters, such as

acceleration and angular velocity of the golf club, the arrangement comprising: an Inertial Navigation System (INS), having a number of sensors, at least one being a gyroscope for measuring an acceleration, angular velocity and effect of attraction of gravity on the sporting equipment, communication arrangement for communicating with a computer unit for receiving and storing relevant data and provided for calculating compensation for the effect of attraction of gravity and quantifying the motion of the club, at least one accelerometer, temperature sensor, gyroscope, amplifiers and filters, the accelerometer and gyroscope form a time dependent sensor inputs to the INS, filters for filtering signals from sensors and amplified in amplifiers before they form inputs to an INS filter, wherein at least one of the filters is an extended Kalman filter, comprising a sensor model, a measurement noise model, a processor for dynamics and noise model.

[0053] The estimated output parameters, represented by a vector matrix, are orientations, angular velocities, angular accelerations, positions, velocities, and accelerations respectively, which variables represent the time dependent results from the INS.

Brief Description of Drawings

[0054] In the following, the invention will be further described in a non-limiting way under reference to the accompanying drawings in which:

[0055] FIG. 1 is a block diagram representing the minimum sensor set up in a general INS,

[0056] FIG 2 is a block diagram of a generic INS filter, with lower level corrections included,

[0057] FIG. 3 represents in a schematic way, the grip of a golf club with an attached sensor module,

[0058] FIG. 4 represents in a schematic way, a golf club with attached sensor modules according to the invention, and

[0059] FIG. 5 represents in a schematic way, a golf club used as a control device, according to another aspect of the invention.

DETAILED DESCRIPTION

[0060] As mentioned above, there is an enormous difference between a collection of sensors and an INS. Not any collection of sensors can be "upgraded" to a useful INS, particularly for sporting equipments and especially golf where the above specifications make the problem extremely hard. In general, there are three points to obtain a successful Inertial Navigation System, for achieving the objects of the present invention.

[0061] A sufficient number of inertial sensors must be present to measure and account for all relevant accelerations and rotations of the system. In this case three-dimensional accelerations and angular velocities. This enables the correct transformation of coordinates from the sensor system to the fixed navigation system, while continuously computing the movement-parameters.

[0062] All sensors must measure their respective acceleration or rotation sufficiently close to the truth, not to render the subsequent computations and transformations useless. This normally means that a host of unwanted effects in the raw sensor signals first must be identified, and compensated for, before the information can be further processed. The unwanted effects must include effects due to temperature. Normally, imperfections of the sensors themselves, like non-linearities, poorly known direction of sensitivity and electric drifts, must be accounted for. Furthermore, imperfections in the sensor system assembly, such as imperfect mounting, will give rise to poorly known directions of sensitivity and sensor positions and perhaps to an imperfect transmission of forces through the assembly. Finally, it is imperative to know the location of the sensors as well as possible to be able to include the ef-

fects of angular accelerations and Coriolis forces that always occur in distributed sensor systems.

[0063] All sensors must be initialized properly prior to actual measurement and tracking of movement parameters. This initialization serves to remove as much as possible of the unwanted but ever-present offset. Assuming an absolutely still INS prior to measurement, the gyro offset is partly due to electrical offset and partly to the Earth's rotation. In the application for golf, the Earth's rotation can be ignored and hence this offset level can simply be subtracted during the later tracking. The offset of the accelerometer, however, is partly due to electrical offset and partly to the Earth's gravitation. The gravitation is large and can almost never be ignored, particularly not for golf. To separate the two offsets, the orientation of the INS versus the direction of gravity, prior to tracking, must be known or the accelerometer must have a sufficiently predictable electrical offset. A predictable electric offset can be compensated for and removed and hence the direction of gravity can be computed and compensated for. In practice, the accelerometers that are suitable for precise measurements of a fast changing acceleration seldom have a predictable electric offset for long periods of time. In the

application for golf the electrical offset must be predictable over time periods of minutes, if not for hours. The solution is often to incorporate a third type of sensor called an inclinometer. The inclinometer has a very predictable offset over longer periods of time so it can measure the orientation of the INS versus the g-vector prior to tracking. The inclinometers generally rely on extreme low-pass filtering and a narrow acceleration range to perform well. Hence, they are usually less suitable for later tracking. Another way to overcome the offset problem is to fix the INS in a well-defined orientation, with respect to gravity, shortly prior to tracking.

[0064] The block diagram of Fig. 1 represents the minimum sensor set up 10 in a general INS. It comprises at least one accelerometer input 11, temperature sensor input 12 and gyroscope input 13. The accelerometers and gyroscopes form the analogue time dependent sensor inputs to an INS. The actual sensors are generally filtered in low-pass filters 14a-14c, amplified in amplifiers 15a-15c and digitized in analogue to digital converters before they form inputs to an INS filter. Furthermore, the signals are perhaps stored in a memory (not shown).

[0065] Fig. 2 illustrates the block diagram of a generic INS filter

20, with lower level corrections included. The filter, e.g. build as an extended Kalman filter, comprises a sensor model 21, a measurement noise model 22, a processor for dynamics 21 and a processor for noise model 24. The time dependent sensor signals arrive directly from the hardware part of the INS, as illustrated in Fig. 1. The calibration data are typically offsets, scale factors and the directions of sensitivity of the physical sensors. The estimated output parameters, represented by a vector matrix 25, are the orientations, angular velocities, angular accelerations, positions, velocities, and accelerations respectively. These variables represent the time dependent results from the INS. It is obvious that the Kalman filter is given as an example and other filter types can be used to achieve same results.

[0066] One feature of the INS of the invention is its ability to convert measured quantities between different coordinate systems.

[0067] In case of a golf club, for example, in principle there can be three types of coordinate systems that need to be covered in this context: the navigation system, i.e. the center of the golf ball, the club system, i.e. the head or grip, and a representative sensor system. The sensor coordinate

system defines the axis of sensitivity and the location of a given sensor, thus there is one sensor system for each sensor used in the model.

[0068] It should be appreciated that number of sensors used can be varied to cover the needs of the measurement, e.g. if two motion parameters are needed to be measured then only a setup of sensors sufficient for measuring two parameters (e.g. in two directions) are needed. Thus, one or several sensor setups can be used. However, in the examples given, references are usually made to a three-dimensional (three coordinates) system.

[0069] Fig. 3 represents the grip 30 of a golf club 31 with an attached sensor module 32. The sensor module, in this case shaped as a ball, can obviously be located in other places on a club, e.g. inside the grip, inside the handle or the club head. Several modules can also be provided simultaneously. The three typical coordinate systems are displayed.

[0070] As depicted in Fig. 3, the coordinate systems mentioned above are hereafter referred to as: $O_N XYZ$ (the navigation system), a $O_{CSj} xyz$ (the club system) and $O_{si} x_i y_i z_i$ (the sensor system). In Fig. 3, the club frame is represented by the grip coordinate system, CS1, but in principle could

also represent the head system, CS2. The sensors are enumerated by the index i and are rigidly fixed close to the handle in an attached sensor module.

[0071] However, one is not interested in the results that are expressed in the sensor system but only interested in what happens or has happened in the navigation system, i.e. where the club and what the angle of the club head are, with respect to the ball. This is a transformation from the sensor system to a fixed system, e.g., with respect to the boll, flag or any other fixed object in the environment of the player.

[0072] An advantages application for INS according to the present invention is implementation in a golf club, thus allowing analyze of a golf stroke, such as a swing. The main reason is that the motion has a short duration, is well defined, is easily repeated on command, and occurs within relative narrow tolerances of motion.

[0073] The short duration is important because the interesting coordinates, position and angle, are computed through a series of integrations.

[0074] The ever-present noise then propagates an error in position that grows as the time squared. Furthermore, any other sensor error, such as various offsets and sensor im-

perfections, contribute to the same errors.

[0075] Long-term tracking is the very difficult problem in INS and is normally solved by periodic coordinate updates from other measurement sources.

[0076] A golf swing always begins with the aiming at the ball, just before the back motion (swing) begins. There forward motion is always a downward motion in the direction of the ball as well as a hit. The motion always finishes with a smooth follow-through. The motion is always smooth because the human body is bad at generating fast discontinuities once in motion. All these features, and several more, make it simpler to select time periods in which the sensor can be initialized, i.e. when offsets can be cancelled and initial positions and orientations can be established.

[0077] The trimming of the entire INS is immensely simplified by the repletion factor in golf. One can basically keep repeating an almost identical motion until the many parts of the INS are optimized.

[0078] The relatively good knowledge of what the swing will look like, before the actual swing occurs, provides the Kalman filter with powerful information that increases the precision of the final result. A golf swing is much easier to

track than a perfectly random motion. In addition, the sensor ranges, bias points and orientations can be carefully trimmed to optimize their golf-performance. This, of course, precludes measuring a different motion with the same system.

[0079] The hardware part 10 of the INS is mounted on or most preferably inside the golf club 11 shaft 12 or inside the handle 13 or the club head 14, as illustrated in Fig. 4. Thus the sensors can be distributed within the golf club (or other sporting equipment). The entire device is then calibrated on an accurate rate table and, if necessary, on a shaker table or linear acceleration stage according to IEEE (Institute of Electrical and Electronics Engineers) standards.

[0080] A computer unit 14, residing nearby (or integrated inside the club, not shown), holds much of the signal processing power and substantial part of the INS software algorithms (Kalman filter) and communicates with the hardware, either remotely or by electric connection. The computer unit can be a conventional PC, laptop, handheld computer or any other type, comprising processing unit, memory, I/O unit, and storing unit for receiving and processing data from the INS. In case the sensors are distributed within

the golf club, the information is processed centrally in the computer. A memory unit can be arranged in the club to store data in the club and transmit it to the computer in a later stage. The communication between the club and the computer is achieved through RF, IR, etc.

[0081] In the case of a golf application, the data can be used to simulate a golfer and the computer can be used to quantify for repetitively learning a motion pattern or a motion (when sporting) can be used to expose errors and shortages in motion and store a motion pattern or variables, comparing motion pattern and variables with stored data, to compare the data with results or performances (something accomplished). Using the stored data can help developing better tools and equipments with respect to the movement pattern of the user. When a teacher is satisfied with a pupils swing, the motion pattern can be stored. Then, the pupil can at anytime train the swings and compare it with the stored data. Errors and defects become the obvious. The pupil and the teacher can compare the results of the swings, for example hooks or slices, with the quantified movements and or conclusions with it conclusions quantify the gesture and pull development. The player can obtain feedback directly in the

quantified motion about various news (changes) in the swing or the equipment. These news can be a different range between the leg and the boll, a different power in the swing, angle of the wrist before the forward motion, a new grip of the handle, a new club, different shows or different ground. The feedback can be obtained after follow-up analyses or also through a signal before, during or after the motion. These signals can be triggered by differences in computed parameters in the stored motion and actual motion. This can be used to practice driving position, part of movement or body orientation during the swing. A user can compare his swing with an expert swing. Characteristics of a swing can be translated to quantified parameters, thus allowing other judgment possibilities.

[0082] Prior to swing, the INS is initialized for a few seconds by holding the club absolutely still in a well-defined position. The offsets of the gyros are here simply removed by keeping them still, as the effect of Earth's rotation (gravity force) is negligible. The offsets of the accelerometers are removed by comparison to the known effect of gravity on each sensor. A number of inclinometers or low-g accelerometers, especially suitable to resolve effects of

gravity, in the INS may aid in this initialization.

[0083] Immediately prior to a swing, the player normally aims at the ball in the direction of the flag for a few seconds, which is a way for the sensors to define the direction toward the flag. Now, the back swing starts and all the sensors are continuously active and measuring accelerations and rotational velocities. In addition, auxiliary data such as temperature is also measured. The data collection unit discriticizes the data, performs rudimentary signal processing, and finally stores the data in an internal memory. Directly after the completed swing, all stored data is transferred to the computer.

[0084] The digital signal processing is perfected in the computer, several sensor software compensations are performed, and suitable transformations of coordinate frame are performed. Finally, the data from all the sensors is filtered together in the main INS algorithm, the Kalman filter. Golf specific information, such as maximum velocity at a point or other restrictions known from the study of many golf swings, may also enter the filter at this time. Furthermore, data from external sensors, like magnetic coils near the ball or radar speeds, may also provide the filter with useful information. This filter then returns computed values

for velocity, position, angular acceleration, and angle in the navigation frame. All these values are discrete, for each time step, and are available in the three space coordinates, both for the accelerometers and for the gyroscopes. All is stored on the computer and can conveniently be graphed on demand.

[0085] This information in the computer can now be called a complete record of one golf swing. This record is unique and depends on the player and ambient conditions such as equipment, the course, and the weather.

[0086] The information from the INS, just like from any other measuring equipment, will always contain an error. The precision and accuracy of the INS will ultimately set a limit to the measured and computed results.

[0087] By keeping all of the ambient conditions constant a player can study his golf swing by comparison of the exhaustive records from several swings. This study may indicate inconsistencies in the swing or deviations compared to swings where a coach has provided human quality information.

[0088] By keeping the swing as constant as possible, such as professional players are skilled in doing, various ambient conditions can be studied through comparison of records.

The club or the golf shoes may have changed. Only the imagination sets the limit as to how the INS can improve performance.

[0089] The temperature measurement is used to compensate the values obtained from the sensors. Both ambient and sensor temperatures can be measured. A temperature sensor and compensation can be integrated within the sensor by the sensor manufacturer, by the system supplier, who adds a measurement/compensation device or by the user of the equipment who adds a digital or analogue device for measurement, e.g. in form of digital thermometer or a sticker on the sensors. In the latter case the user must measure, compensate and calibrate the sensors for the temperature by him.

[0090] The temperature is measured actively substantially on all sensors or the entire system (filters, processors etc.). The system can thus be calibrated fixed for a certain temperature, independent of the ambient temperature or self-heating. Thus, much higher precision is obtained.

[0091] The temperature compensation can be obtained in two ways: The entire system is rotated on, e.g. a rotation table in a climatic chamber,

[0092] Three signals are obtained: The through value from the

rotation table (rotation velocity), Output from first sensor (S1), The temperature (T) of S1.

[0093] Then a graph for each coordinate system for each temperature with a speed of rotation on e.g. x-axis, and the output of S1 on, e.g. y-axis is provided. If output of S1 varies modestly with respect to the speed of the rotation (for a fixed T), the speed of the rotation is described as a function: RS(S1). If the output varies unreasonably, a table can be generated. Steps 3-5 are repeated for different temperatures. The sensor is then integrated into the system (e.g. a golf club). When using the system in the real environment, two signals $S1_R$ and T_R are obtained. T_R decides which table or function to be used and S1R points out the speed of the rotation in the table or the function. This is the calibrated rotation speed. Experiments have shown that there is a connection between the temperature and S1. This means that the temperature measurement must be conducted very close to the sensors, i.e. in reality a temperature measurement for each sensor in the system. However, it is possible to thermally connect the sensors and thus obtain one value.

[0094] Another example of an application is illustrated in Fig. 5, in which a golf club 12 comprising the arrangement 10 of

the invention, integrated inside the club head 14, is used as a cursor control device on a computer display 15. The cursor, here illustrated as a club icon 16, is controlled by communicating the position, velocity, angular velocity etc., of the club to a processing interface of the computer, which translates the club data to a set of position data to be displayed. This arrangement (not limited to golf clubs) can be used both for gaming and practice, e.g. in a golf simulator.

[0095] In a preferred embodiment, when tracking at the end of the shaft, the position should be known to within 10 mm, preferably 5 mm throughout the entire swing. All angles at the end of the swing should be known to within 2°, preferably 0.5-1°. The linear and angular velocity of the club should be known to within 2%, preferably 1% of its maximum values. The system sample rate must exceed 120 samples/sec., preferably 250 samples/second to resolve the interesting final part of the motion. When tracking at the club head the position should be known to within 10 mm, preferably 2-5 mm to usefully resolve the impact of the ball. The loft/lie angle should be resolved to within ±1°, preferably ±0.5°. The open/close angle should be resolved to within ±0.5°, preferably ±0.1°. The angular

rates should be known to within 2%, preferably 1% of their maximum values. The linear velocity should be known to within 1mph, preferably 0.5 mph.

[0096] Even though a golf club is exemplified herein, it is obvious that the arrangement and method of the invention can be implemented in other sporting equipments such as ice-hockey stick, baseball bat, tennis/badminton/table tennis rackets, etc., or any other equipment in which a motion analyses is needed. Moreover, the invention can be used in any other moving objects such as a vehicle, airplane etc.

[0097] The invention is not limited the shown embodiments but can be varied in a number of ways without departing from the scope of the appended claims and the arrangement and the method can be implemented in various ways depending on application, functional units, needs and requirements etc.

[0098] The quantifications of the invention(s) disclosed herein, as well as the protection being sought therefore, in terms of scope and breadth, can be characterized in a plurality of ways. Examples are included below in the following exemplary claim sets:

[0099] SET ONE

[0100] 1. An arrangement for detecting movement-parameters in a moving object, said parameters comprising acceleration and angular velocity of said object, said arrangement comprising an Inertial Navigation System (INS), comprising at least one gyroscope and accelerometer for measuring an acceleration, angular velocity and effect of attraction of gravity on said object.

[0101] 2. The arrangement of claim 1, comprising means for communicating with a computer unit for receiving and storing relevant data.

[0102] 3. The arrangement of claim 1, comprising means for communicating with a computer unit for compensating for said effect of attraction of gravity.

[0103] 4. The arrangement of claim 2, wherein said data quantifies a movement by computing results and variables from said sensors.

[0104] 5. The arrangement of claim 1, wherein a minimum sensor set up comprises at least one accelerometer, temperature sensor, gyroscope, amplifiers and filters.

[0105] 6. The arrangement of claim 5, wherein said accelerometer and gyroscope form a time dependent sensor inputs to said INS.

[0106] 7. The arrangement of claim 1, wherein signals from sen-

sors are generally filtered in filters and amplified in amplifiers before they form inputs to an INS filter.

[0107] 8. The arrangement of claim 7, wherein at least one of said filters is an extended Kalman filter, comprising a sensor model, a measurement noise model, a processor for dynamics and a processor for noise model.

[0108] 9. The arrangement of claim 8, wherein calibration data are used comprises on or several of offsets, scale factors and the directions of sensitivity of physical sensors.

[0109] 10. The arrangement of claim 9, wherein estimated output parameters, represented by a vector matrix, are one or several of orientations, angular velocities, angular accelerations, positions, velocities, and accelerations respectively, which variables represent time dependent results from the INS.

[0110] 11. The arrangement of claim 1, wherein said object is sporting equipment.

[0111] 12. The arrangement of claim 1, wherein said equipment is a golf club.

[0112] 13. The arrangement of claim 12, wherein three coordinate systems are used: a navigation system, a club system and a sensor system.

[0113] 14. The arrangement of claim 12, wherein said navigation

system defines a position of the club an angle of the club head with respect to a ball.

[0114] 15. The arrangement of claim 12, wherein said sensor is arranged in at least one of a handle, shaft or head of said golf club.

[0115] 16. The arrangement of claim 2 or 3, wherein said computer unit provides for at least one of:- computing and storing movement data about said object, or - comparison between new and stored movement data.

[0116] SET TWO

[0117] 17. A system for detecting and analyzing motion data comprising acceleration and angular velocity, the system comprising: an arrangement for detecting movement-parameters of an equipment, said arrangement comprising: an Inertial Navigation System (INS), comprising a number of sensors: at least one gyroscope and accelerometer for measuring acceleration and angular velocity and effect of attraction of gravity on said equipment, a computer unit communicating with said arrangement and comprising processor for processing data received from said arrangement and compensating for said effect of attraction of gravity on said equipment.

[0118] 18. The system of claim 17, wherein said computer unit

comprises audio and video output arrangement for communication with a user of said equipment.

[0119] 19. The system of claim 17, wherein said computer unit comprises storing means for storing means for storing data from said arrangement and providing said data for education or training of said user.

[0120] 20. The system of claim 17, wherein said equipment is one of a golf club, ice-hockey stick, baseball bat, tennis/badminton/table tennis rackets, fishing rod.

[0121] 21. The system according to claims 18, wherein said sensor system has a specific coordinate system, which is transformed to a fixed coordinate system with respect to a fixed point in an environment of said equipment.

[0122] SET THREE

[0123] 22. A golf club comprising an arrangement for detecting movement-parameters of said golf club, said arrangement comprising an Inertial Navigation System (INS), wherein said arrangement further comprises a number of sensors for measuring a acceleration, angular velocity and effect of attraction of gravity on said golf club.

[0124] 23. The golf club of claim 22, comprising means for communication with a computer unit for receiving and storing relevant data.

[0125] 24. The golf club of claim 22, comprising means for communication with a computer unit for compensating for said effect of attraction of gravity.

[0126] 25. The golf club of claim 23, wherein said data quantifies a movement by computing results and variables from said sensors.

[0127] 26. The golf club of claim 22, wherein a minimum sensor set up comprises at least one accelerometer, temperature sensor, gyroscope, amplifiers and filters.

[0128] 27. The golf club of claim 26, wherein said accelerometer and gyroscope form a time dependent sensor inputs to said INS.

[0129] 28. The golf club of claim 22, wherein the actual sensors are generally filtered in filters and amplified in amplifiers before they form inputs to an INS filter.

[0130] 29. The golf club of claim 28, wherein said filter is an extended Kalman filter, comprising a sensor model, a measurement noise model, a processor for dynamics and a processor for noise model.

[0131] 30. The golf club of claim 29, using calibration data comprising offsets, scale factors and directions of sensitivity of physical sensors.

[0132] 31. The golf club of claim 30, wherein estimated output

parameters, represented by a vector matrix, are orientations, angular velocities, angular accelerations, positions, velocities, and accelerations respectively, which variables represent the time dependent results from the INS.

[0133] 32. The golf club of claim 31, wherein three coordinate systems are used: a navigation system, a club system and a sensor system.

[0134] 33. The golf club of claim 32, wherein the navigation system defines a position of the club an angle of a club head with respect to a ball.

[0135] 34. The golf club of claim 32, wherein said sensor is arranged in at least one of a handle, shaft or head of said golf club.

[0136] 35. The golf club of claim 34, wherein when tracking at an end of a shaft, a position is about ≤10 mm, preferably within 5 mm throughout an entire swing.

[0137] 36. The golf club of claim 35, wherein all angles at the end of the swing are within 2°, preferably within 0.5 to 1°.

[0138] 37. The golf club of claim 34, wherein linear and angular velocities of the club are within 2%, preferably within 1% of its maximum values.

[0139] 38. The golf club of claim 34, wherein a sample rate exceeds 120 samples/sec., preferably 250 samples/second

to resolve a final part of the motion.

[0140] 39. The golf club of claim 34, wherein when tracking at the club head the position is within 10 mm, preferably within 2-5 mm.

[0141] 40. The golf club of claim 34, wherein a loft/lie angle is within ±1°, preferably within ±0.5°.

[0142] 41. The golf club of claim 34, wherein an open/close angle is resolved to within ±0.5 °, preferably within ±0.1 °.

[0143] 42. The golf club of claim 34, wherein angular rates are, within about 2% preferably within 1% of their maximum values.

[0144] 43. The golf club of claim 34, wherein a linear velocity is within 1 mph, preferably 0.5 mph.

[0145] SET FOUR

[0146] 44. A method of analyzing a movement of a sporting equipment comprising, the steps of: collecting movement-parameters of said equipment by means of an Inertial Navigation System (INS), by measuring acceleration, an angular velocity and effect of attraction of gravity on said equipment.

[0147] 45. The method of claim 44, comprising further step of compensating for said effect of attraction of gravity.

[0148] 46. The method of claim 44, wherein said equipment is a

golf club, comprising gyro sensors and accelerometer sensors.

[0149] 47. The method of claim 46, comprising the steps of:- prior to a swing initializing said INS by holding said club substantially absolutely still in a well-defined position, - removing offsets of said gyros in said club by keeping them still, - removing offsets of the accelerometers by comparison to the known effect of gravity on each sensor.

[0150] 48. The method of claim 46, comprising the steps of:- immediately prior to a swing, aiming at a ball in a direction of a flag for the sensors to define a direction toward the flag, - continuously activating said sensors in a back swing and measuring accelerations and rotational velocities.

[0151] 49. The method of claim 48, comprising the step of measuring temperatures.

[0152] 50. The method of claim 48, comprising the steps of:- collecting data unit the data is discriticizes, - performing rudimentary signal processing, and- storing the data in an internal memory.

[0153] 51. The method of claim 50, wherein all stored data is transferred to a computer unit after a performed swing.

[0154] 52. The method of claim 44, wherein a three dimensional

acceleration and angular velocity are measured.

[0155] SET FIVE

[0156] 53. A golf club comprising, an arrangement for detecting movement-parameters, such as acceleration and angular velocity of the golf club, said arrangement comprising: an Inertial Navigation System (INS), having a number of sensors, at least one being a gyroscope for measuring an acceleration, angular velocity and effect of attraction of gravity on said sporting equipment, communication arrangement for communicating with a computer unit for receiving and storing relevant data and provided for calculating compensation for said effect of attraction of gravity and quantifying the motion of said club, at least one accelerometer, temperature sensor, gyroscope, amplifiers and filters, said accelerometer and gyroscope form a time dependent sensor inputs to said INS, filters for filtering signals from sensors and amplified in amplifiers before they form inputs to an INS filter, wherein at least one of said filters is an extended Kalman filter, comprising a sensor model, a measurement noise model, a processor for dynamics and noise model.

[0157] 54. The club of claim 53, wherein estimated output parameters, represented by a vector matrix, are orientations,

angular velocities, angular accelerations, positions, velocities, and accelerations respectively, which variables represent the time dependent results from the INS.